Tune Measurement at the Tevatron

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CARE Workshop
12 Dec 2007

Overview

- Challenges in measuring tunes in the Tevatron
  - Physics
  - Detector Requirements
- Type of detectors
  - 21.4 Mhz Schottky
  - 1.7 Ghz Schottky
  - 3D-BBQ (Direct Diode Detector Baseband Tune, not operational)
  - Digital Tune Monitor (not operational, expert only)
- Conclusion

The Tevatron

- The Tevatron is a single beam pipe machine
- 36 bunches of protons collide with 36 bunches of anti-protons
  - Use electrostatic separators to keep the 2 species apart
    - 6 horizontal separators and 7 vertical separators.
  - Protons have approximately 3 times more current than anti-protons
- There are 70 near misses (parasitic crossing points) and 2 head-on collisions at experiments CDF and D0

The Challenges

- 2 species in the same beam pipe.
  - Possible contamination of signals between species
- Must have ability to measure bunch by bunch tunes
  - Bunch separation of ~396 ns between bunches of the same species in each train (3 trains of 12 bunches)

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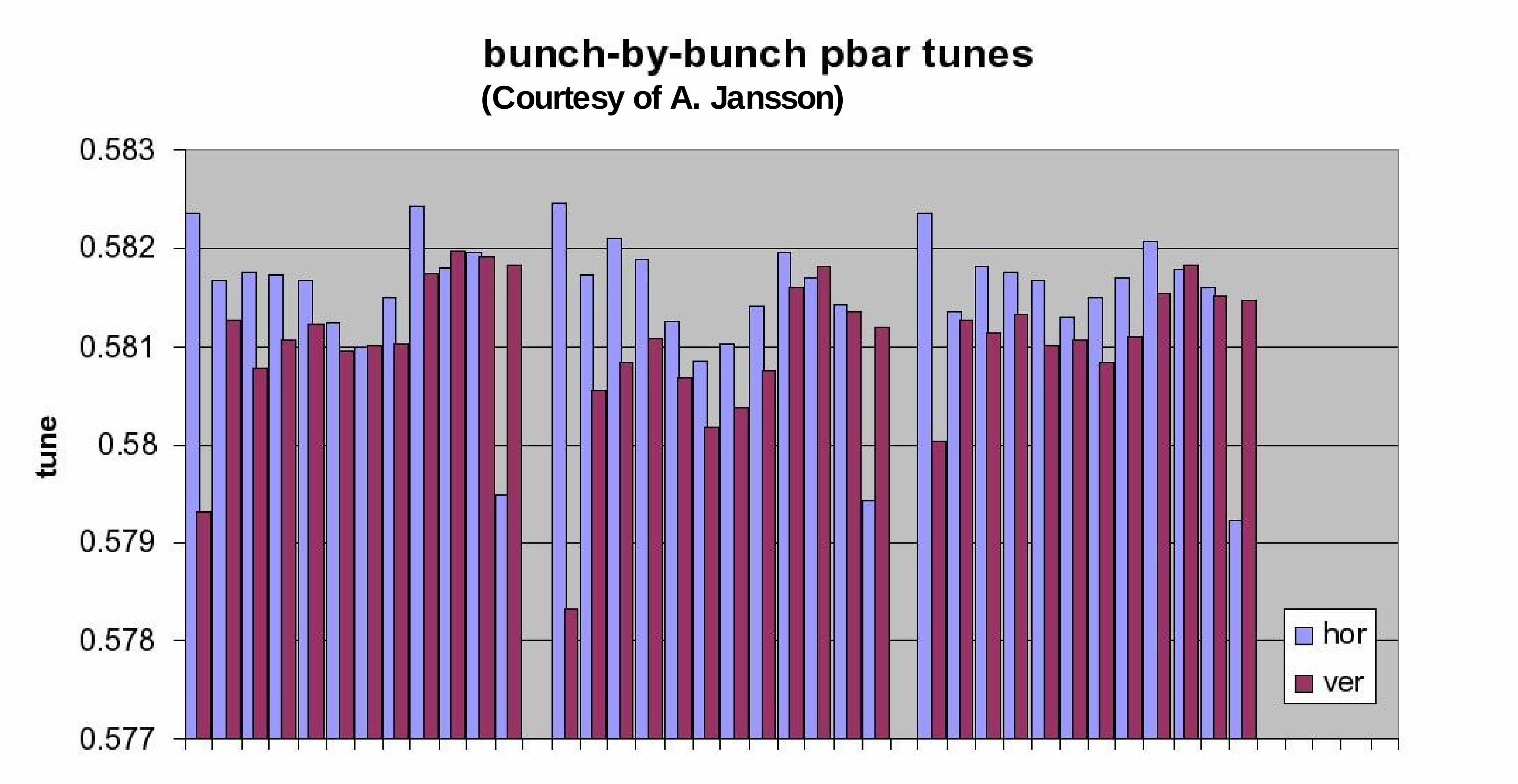
Physics



Beam beam tune shifts. Horz/vert tunes of 1st and last bunch in each train are different.

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The Ideal System

- Must be directional, e.g. Stripline.
- Must be parasitic, i.e. No beam excitation.
- Must be bunch by bunch.
- Must work at injection, up the ramp and thru squeeze.
- Electronics/Software must return data ~1Hz.
- Accuracy 10^{-4}

Pickup Requirements

- Choice of location
  - Select location in the Tevatron where the two species are temporally separated.
- Design pickups with directivity
  - Stripline ~30 dB directivity
- Bandwidth ~100MHz
  - Single bunch signal are distinct.
  - RF gates can be used for bunch by bunch tune measurements
  - Sample only where bunches are (~7.5 MHz)

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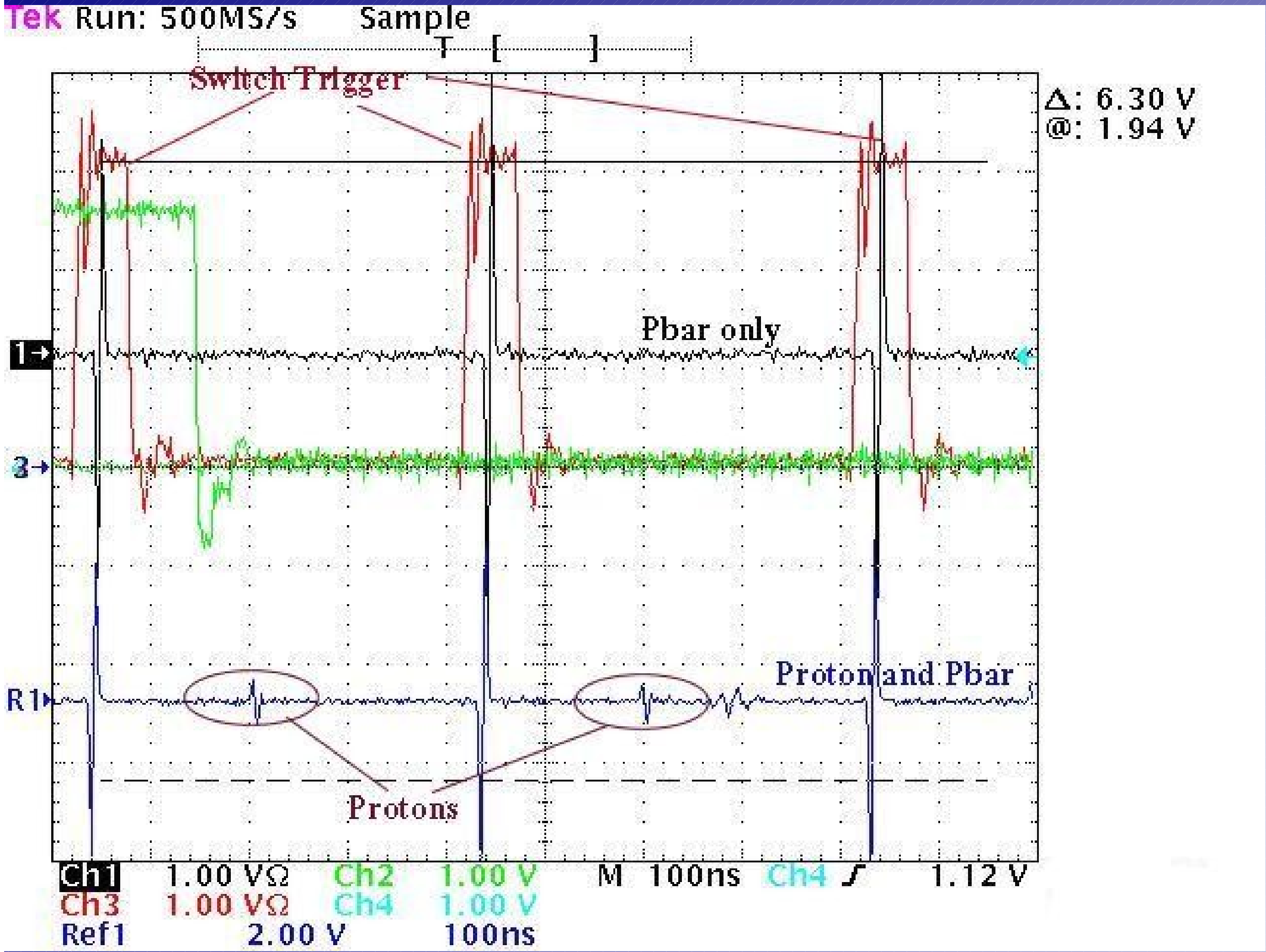
Example with Stripline



- Time separation
- Directivity
- Gating

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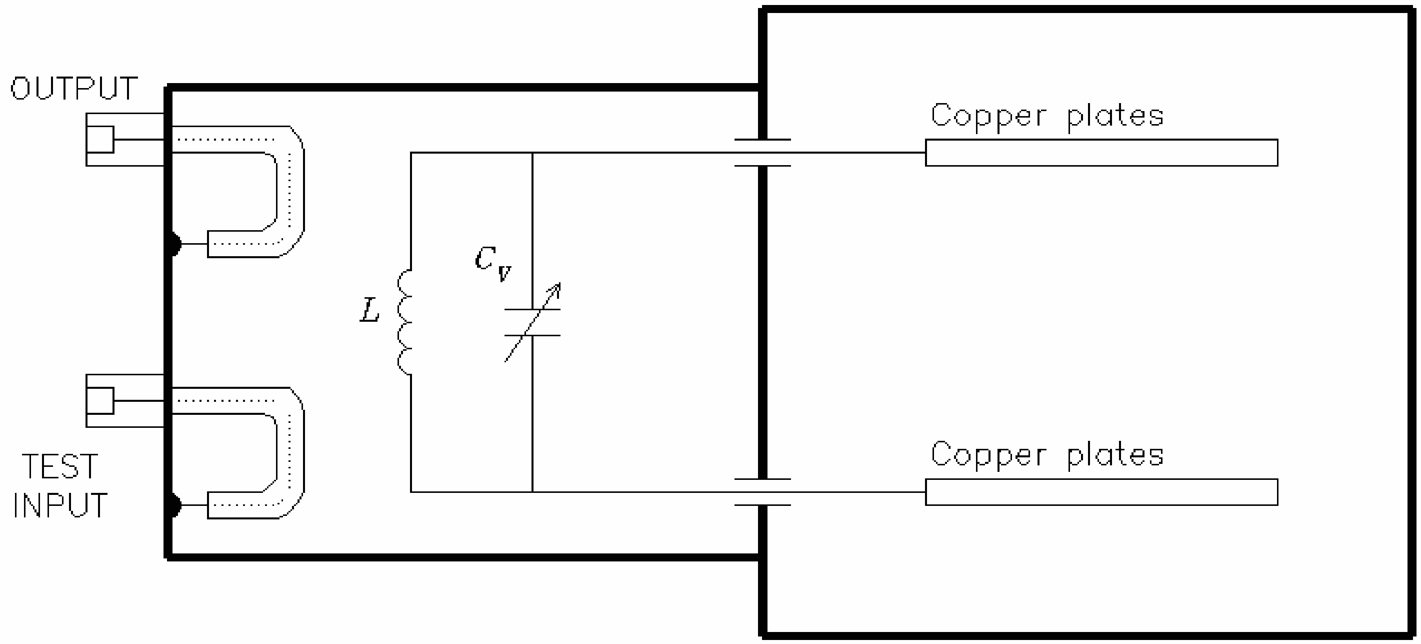
Detectors used in the Tevatron

- 21.4 Mhz Schottky
  - Resonant Detector. Q ~ 370
  - Workhorse of the Tevatron. Standard for measuring proton tunes. Not bunch by bunch.
  - Cannot see pbar tunes without help.
- 1.7 Ghz Schottky
  - Designed with low Q ~ 20 so that RF gating can be used
  - Directional

Detectors used in the Tevatron (cont'd)

- 3D-BBQ (Direct Diode Conversion Baseband Tune)
  - Uses 0.5 m stripline.
  - Uses diode as envelope detector.
  - R&D project in collaboration with CERN under US-LARP.
- Digital Tune Monitor
  - Uses standard 30cm standard Tev. BPM striplines.
  - Brute force digitization.
  - Requires tickling of the beam.

21.4 Mhz Schottky



Courtesy of B. Fellenz

1 m long structure. 6" square, plates 2" wide
21.4 Mhz chosen because narrow band crystal filters easily available

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Limitations of 21.4 Mhz Schottky

- It is not bunch by bunch because of high Q~370.
- It is unable to see pbars without help.
  - Anti-protons must be kicked gently (tickled)
- Contamination of anti-proton signal with proton signal even when looking at anti-proton end of pickup.
  - Other electronic effects which are not well understood.

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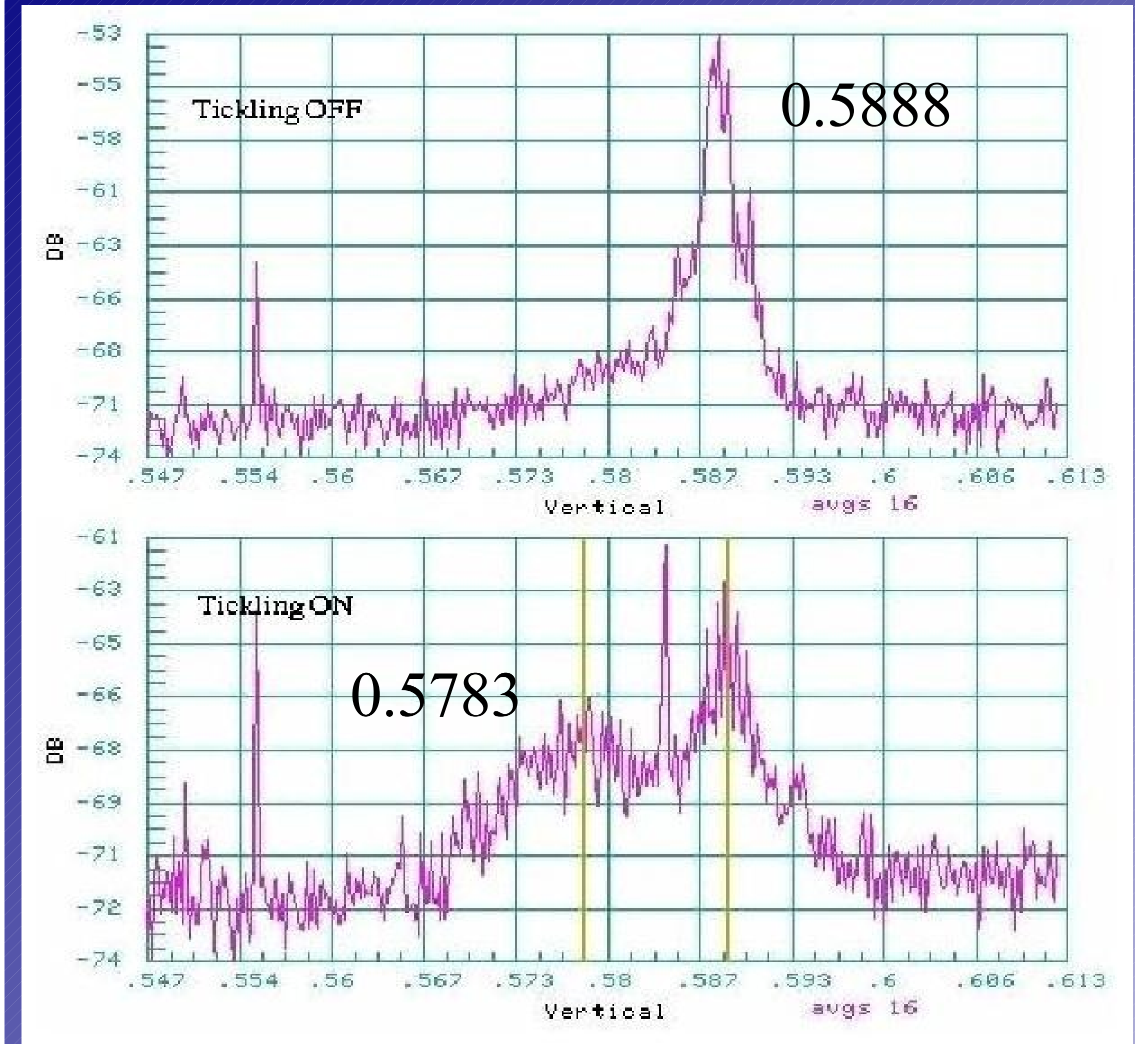
Seeing Anti-protons



- Only anti-proton bunch 24 tickled vertically.
- Contamination from protons.
- Tickling brings anti-proton bunch 24 out of noise floor.
- Other effects which are not well understood.

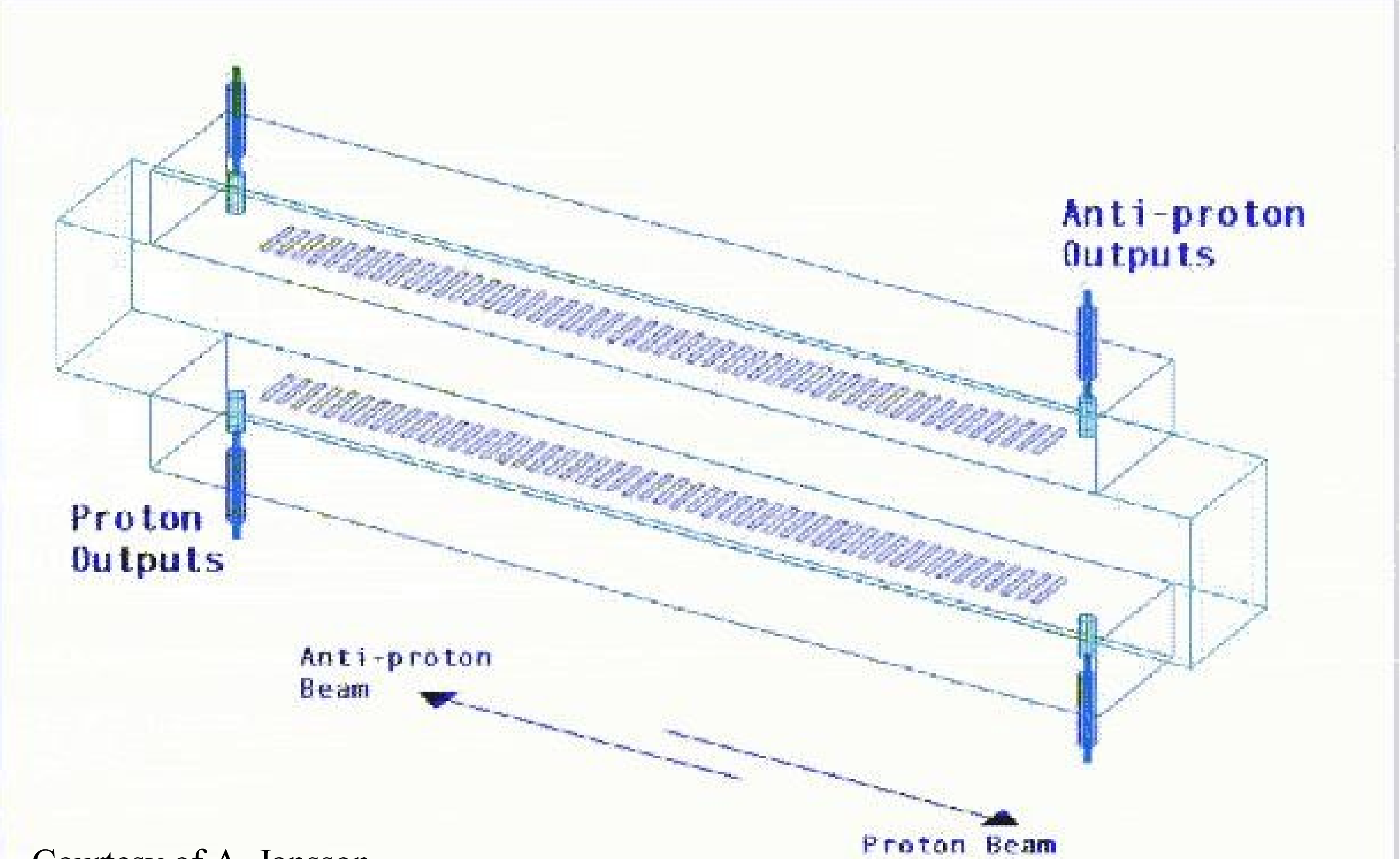
Disadvantages

- Not bunch by bunch.
- Must tickle the anti-protons
  - Causes lifetime issues.
  - Blows up emittance.
  - Can only be used at the end of high energy physics
    - No continuous monitoring of anti-proton tunes

1.7 Ghz Schottky

- Installed in 2002.
- A breakthrough detector in the Tevatron
  - Designed to be bunch by bunch.
  - Designed to be directional.

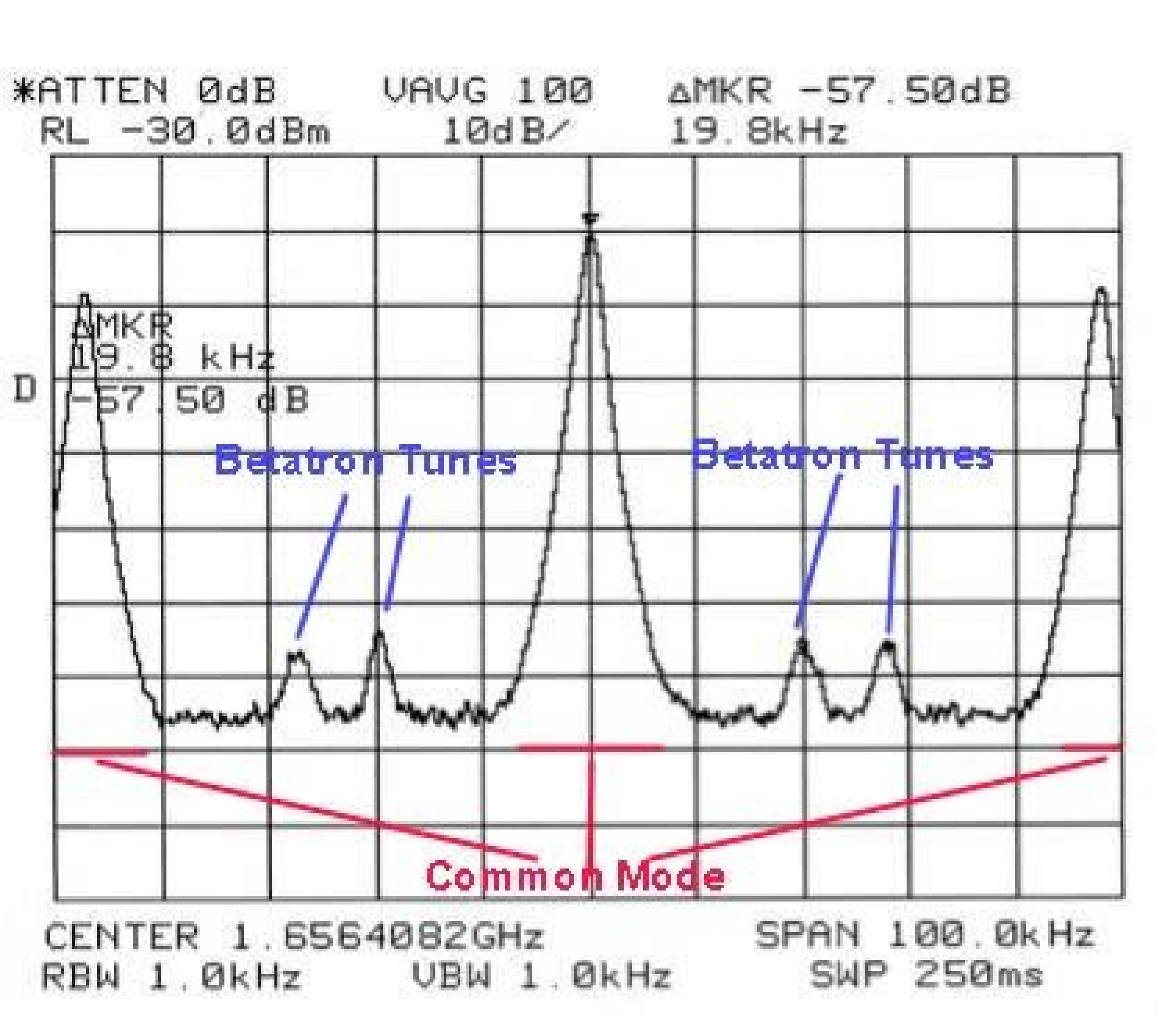
1.7 Ghz Schottky



Courtesy of A. Jansson

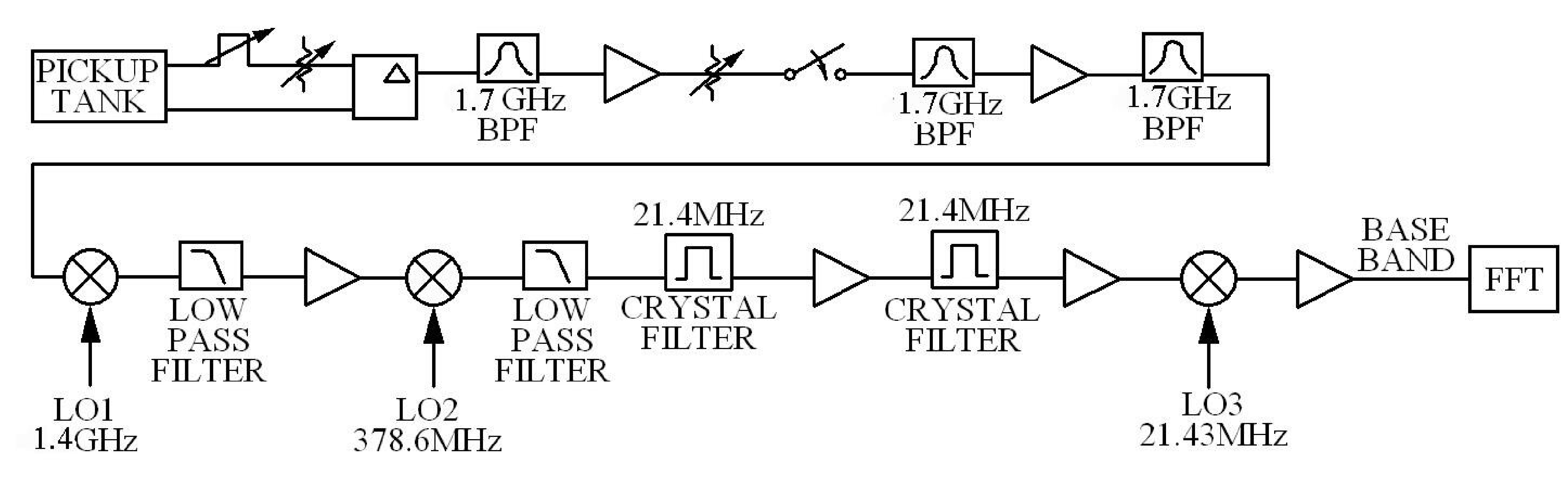
1m x 109mm x 79mm

Large Common Mode Signal



- Large common mode signal in hadron machines.
- Requires 60dB of dynamic range in electronics.

Setup



Note: 3 down conversions.

Courtesy of R. Pasquinelli

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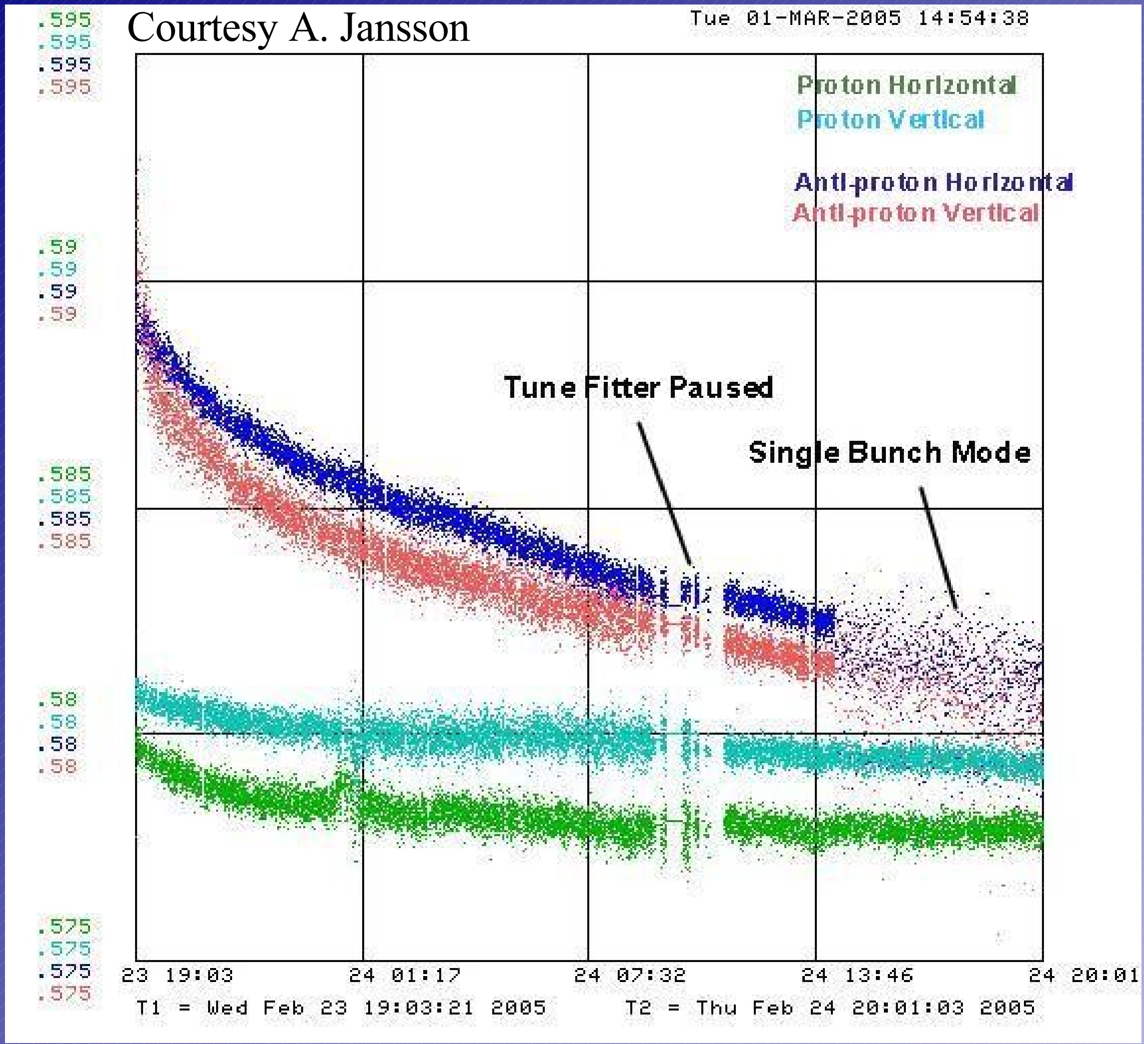
Sophisticated Software

- Instrument is useless to physics without good software.
- Tune fitting software written by P. Lebrun to look at
  - Bunch by bunch tunes
  - Chromaticity
  - Momentum spread
  - Transverse emittance

Tune Evolution During a Store



- Anti-proton tunes are higher ~ 0.01 at the start of the store.
- Proton tunes relatively constant during a store.
- Possibility of simple tune feedback during a store (done by hand right now)

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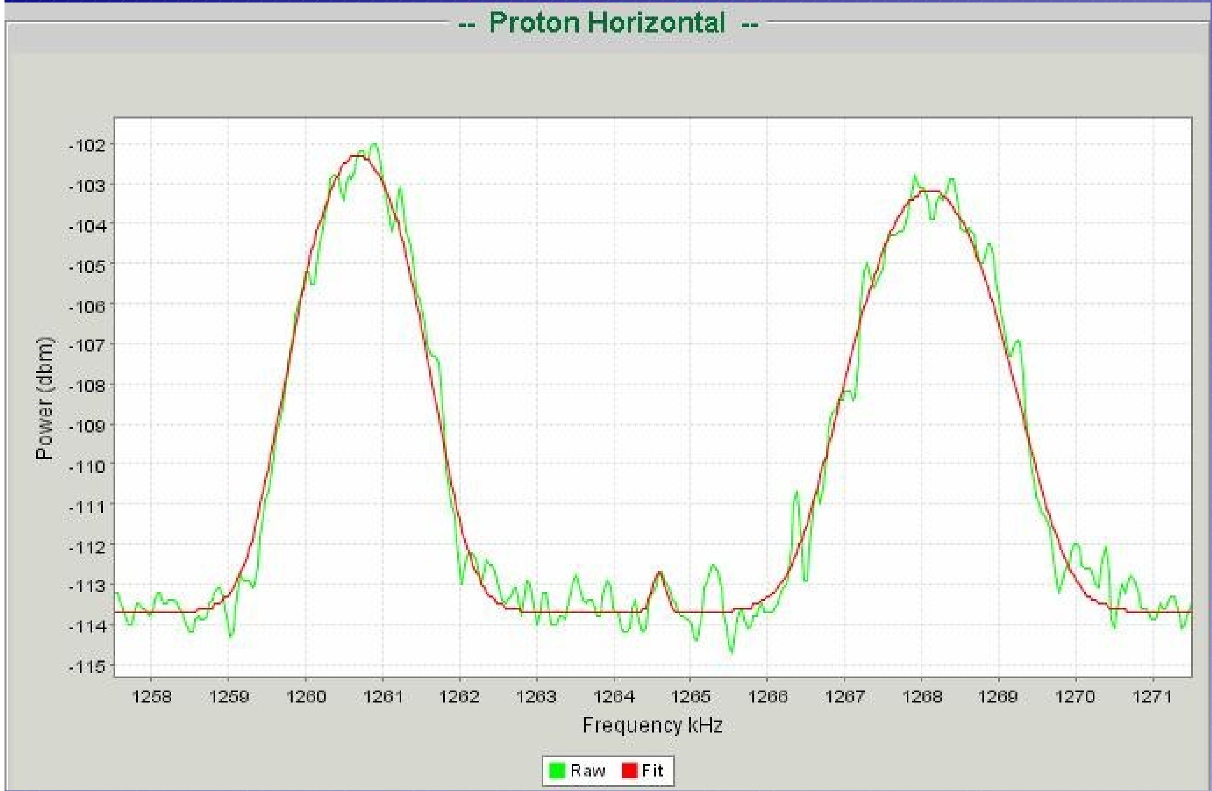
The Signal



Width and height from chromaticity. Average is momentum spread.

- Width of tune (.025) and noise gives rms error of 10^{-4} for 36 bunches and 4×10^{-4} for single bunch.
- Measured tunes are those of zero coupling even if the Tevatron is coupled.
- New CERN type electronics used in downconversion may possibly allow tracking up the ramp and squeeze at LHC. Tevatron ramp and squeeze too fast for tracking. (ramp is 80s)

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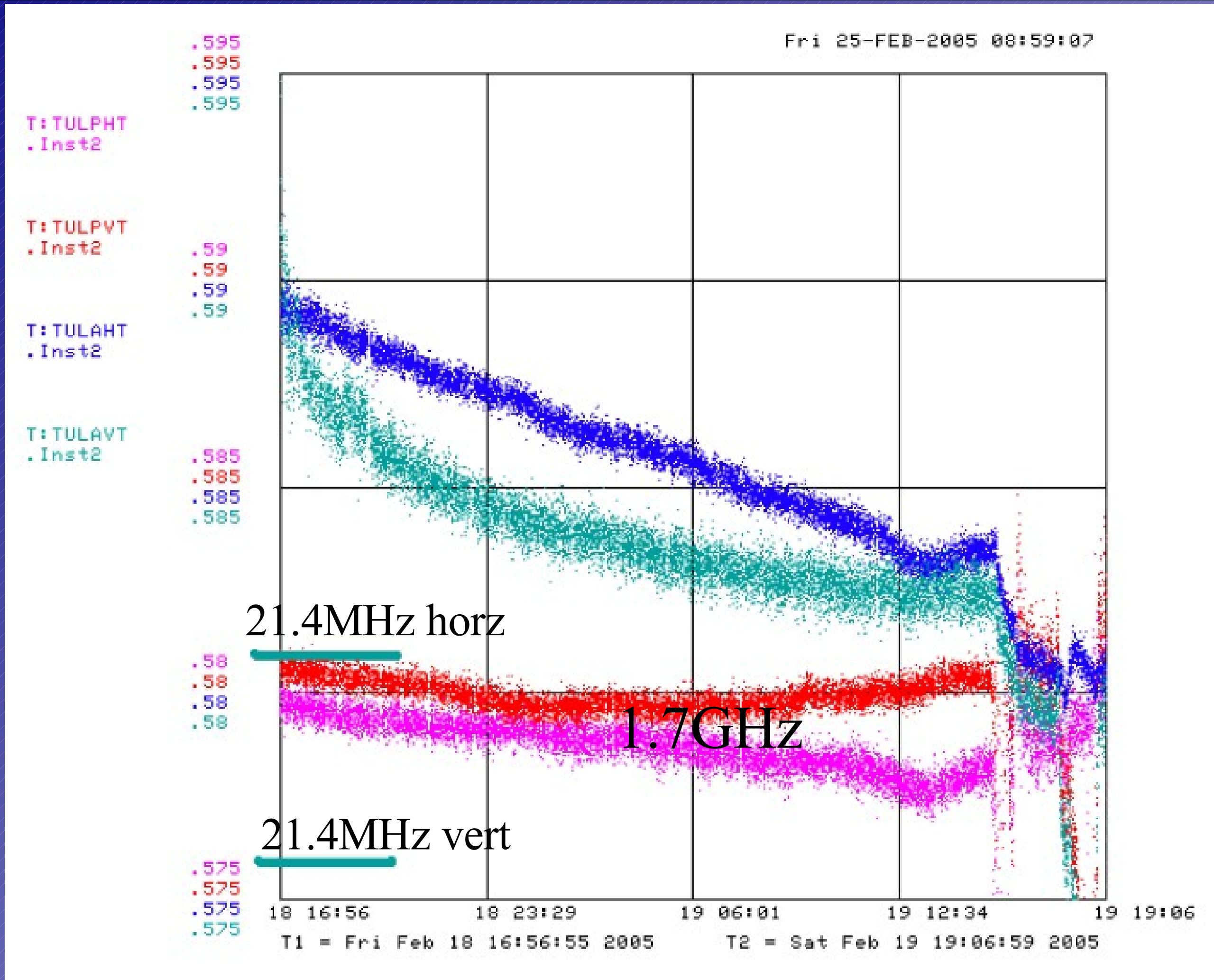
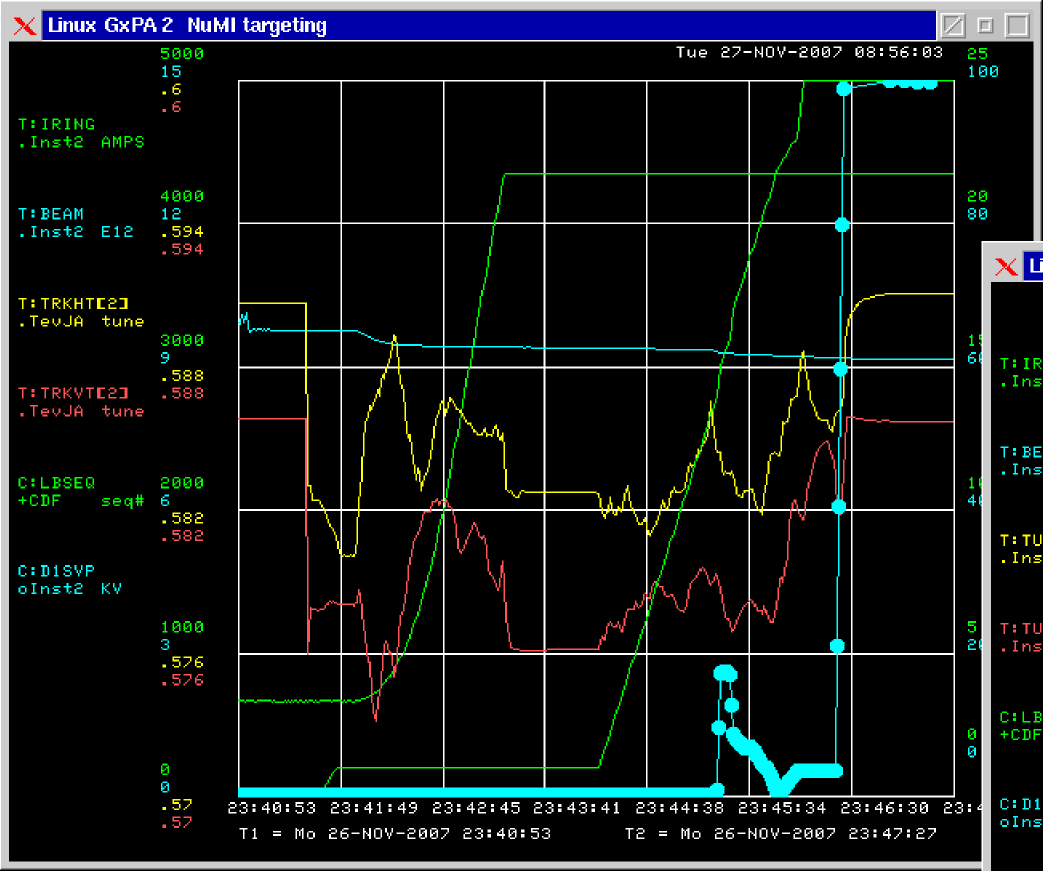
Cannot See Coupling

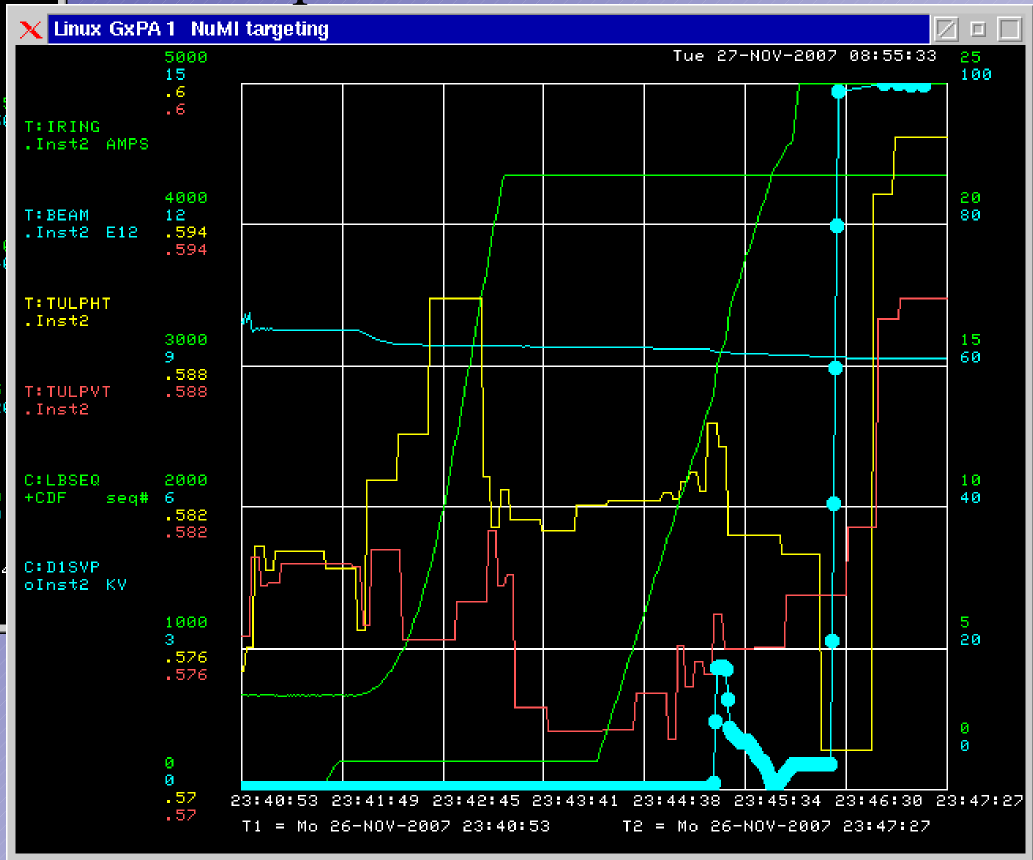


Tune separation much further for 21.4MHz Schottky because of coupling.

Comparing Tune Tracker to 1.7GHz Schottky



Schottky signals disappear because of bubbling up the ramp and squeeze.



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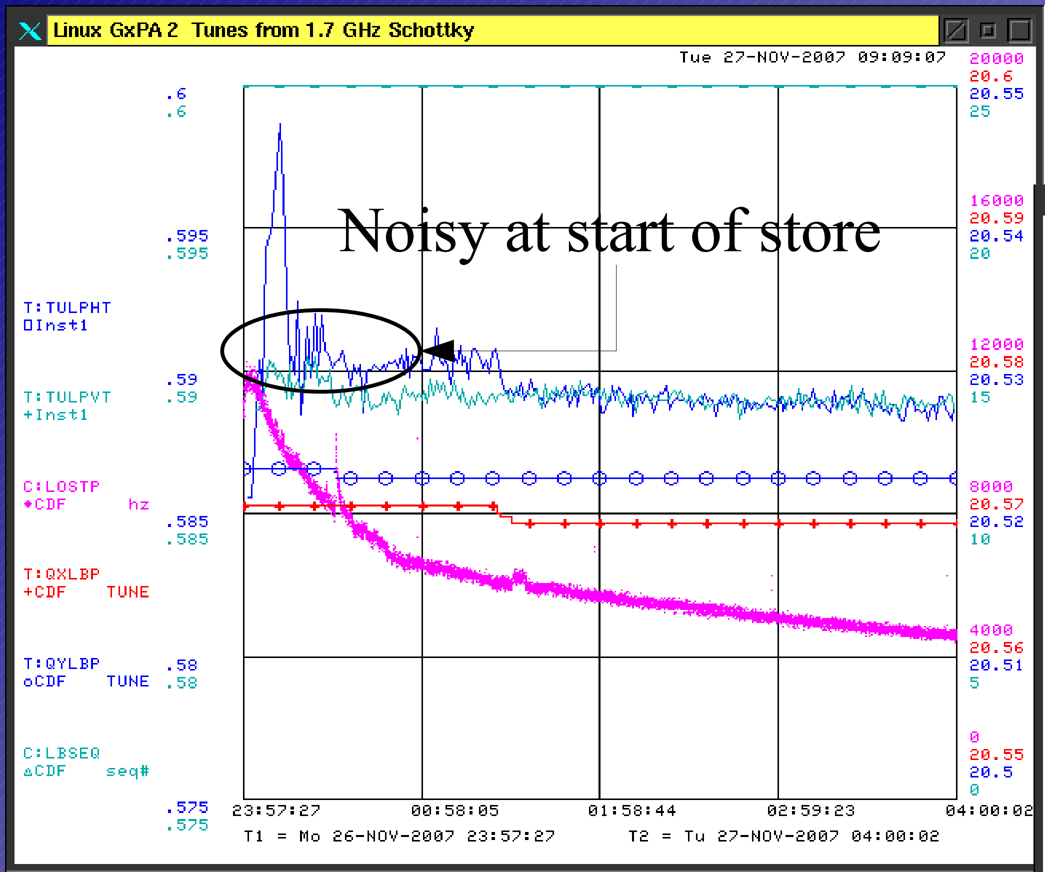
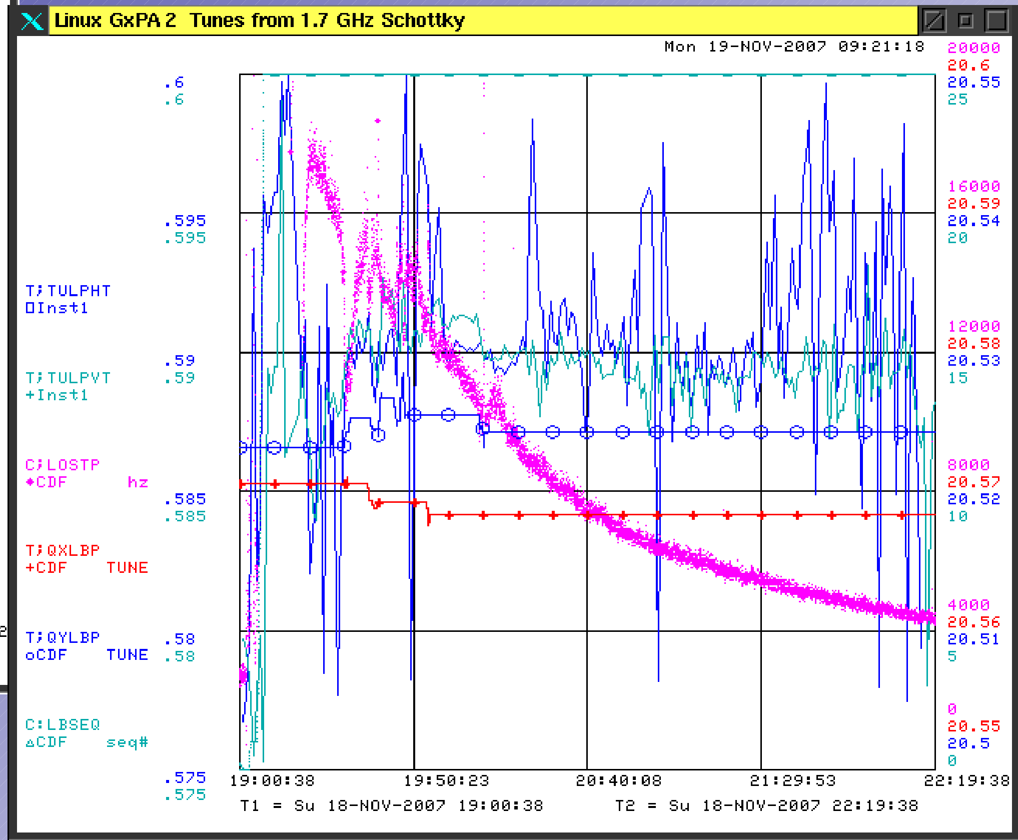
Tuning During Store



Very noisy even 3 hrs into store. Losses?



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3D-BBQ (not operational)

- Developed by M. Gasior (CERN)
- R&D project under US-LARP collaboration
  - Tested at FNAL, RHIC and SPS.
- Not operational at FNAL
  - One student working on this
  - Some interesting “problems”

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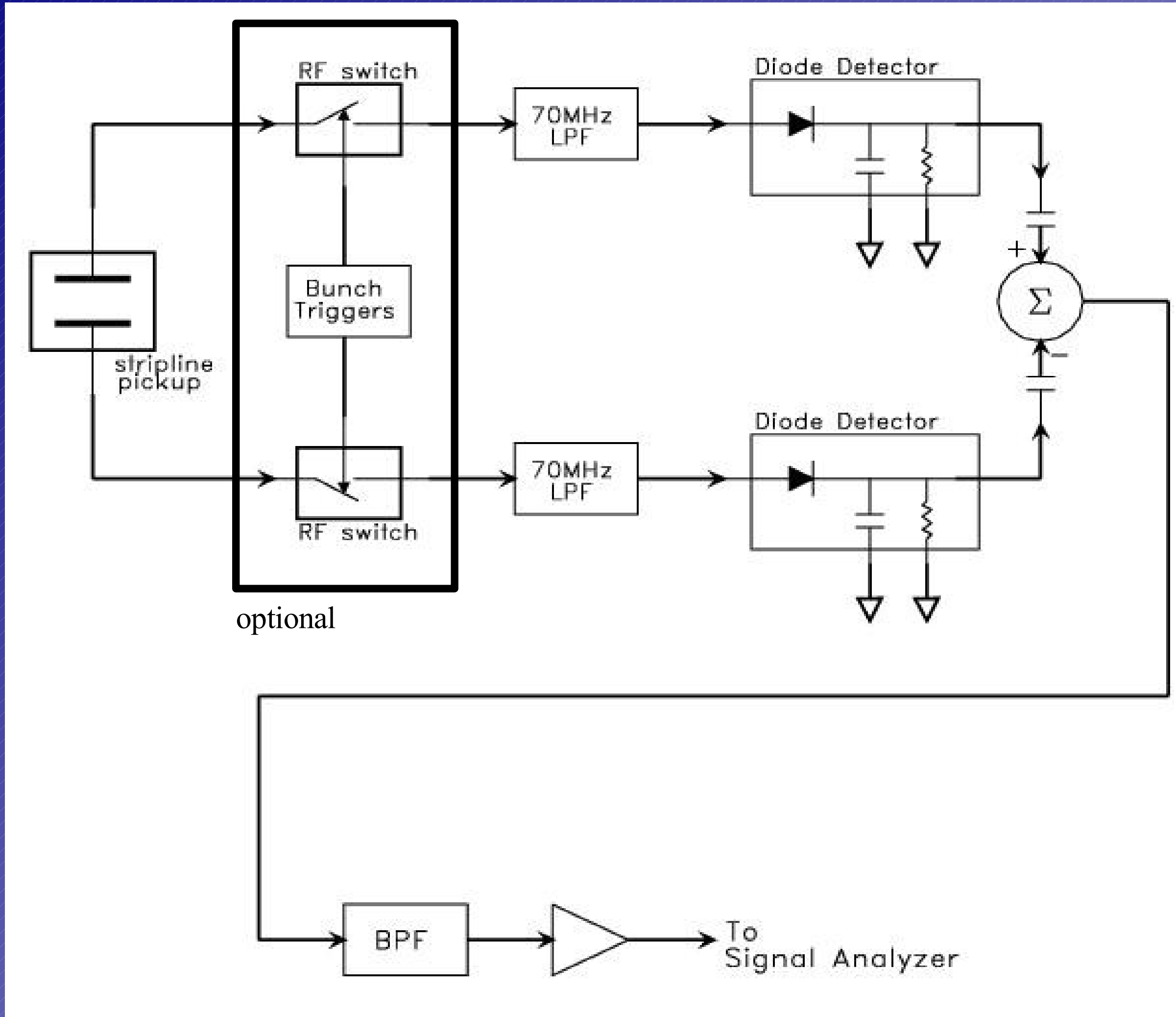
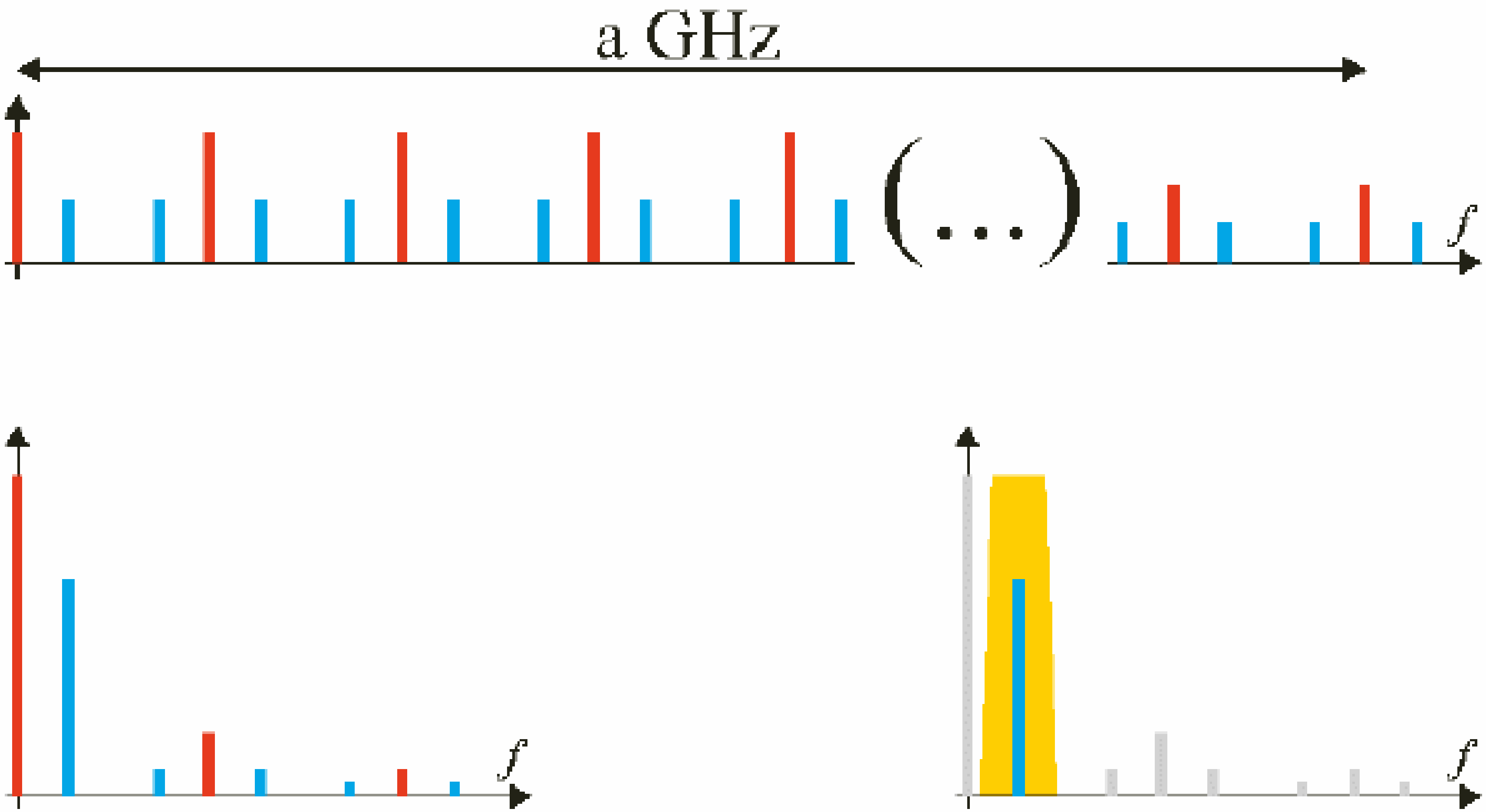
Setup



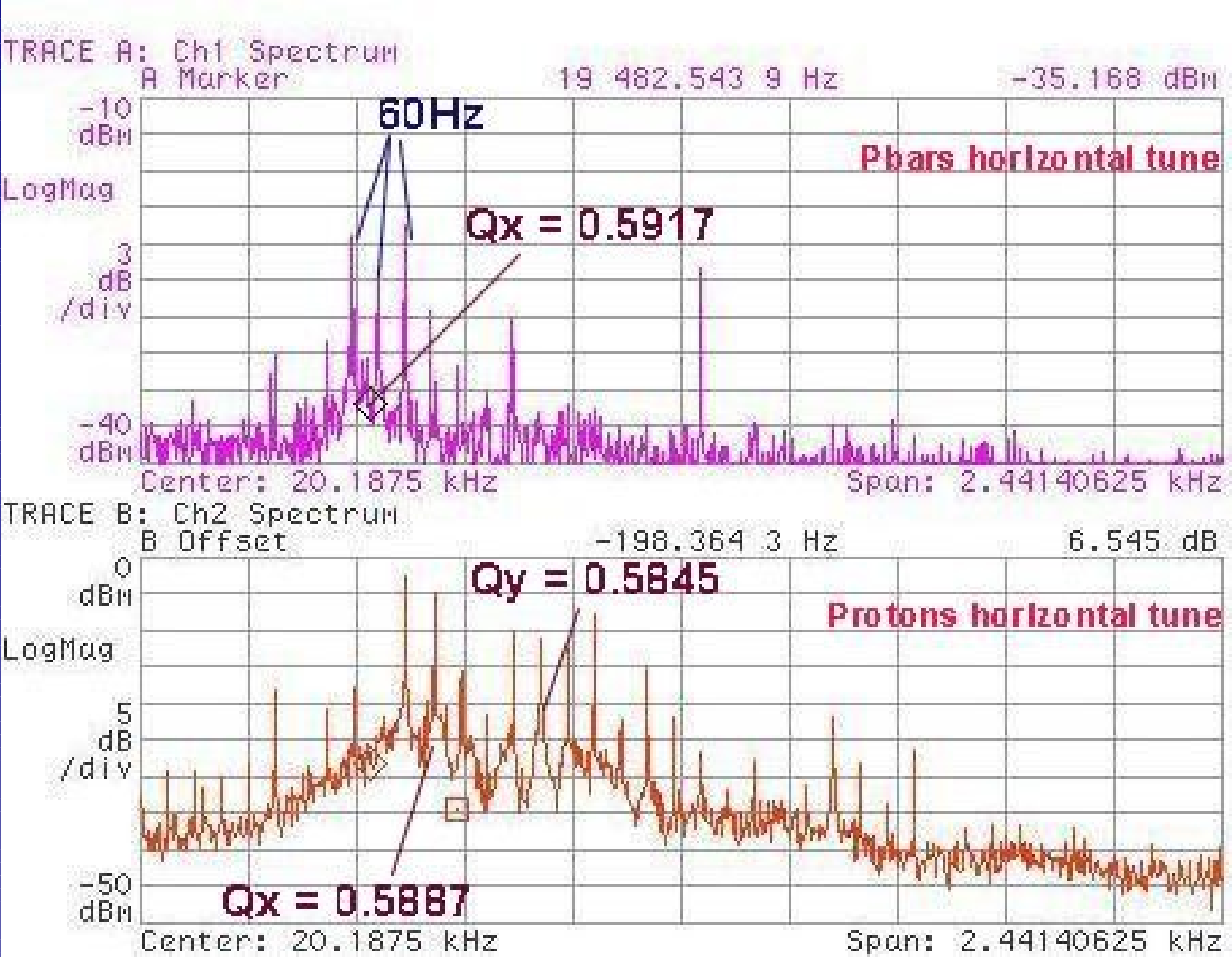
- Diode detector is basically a peak detector.
- BPF attenuates revolution harmonic.
- Stripline pickup gives directionality.
- RF switches gives bunch by bunch tune measurement

Principle

Courtesy M. Gasior

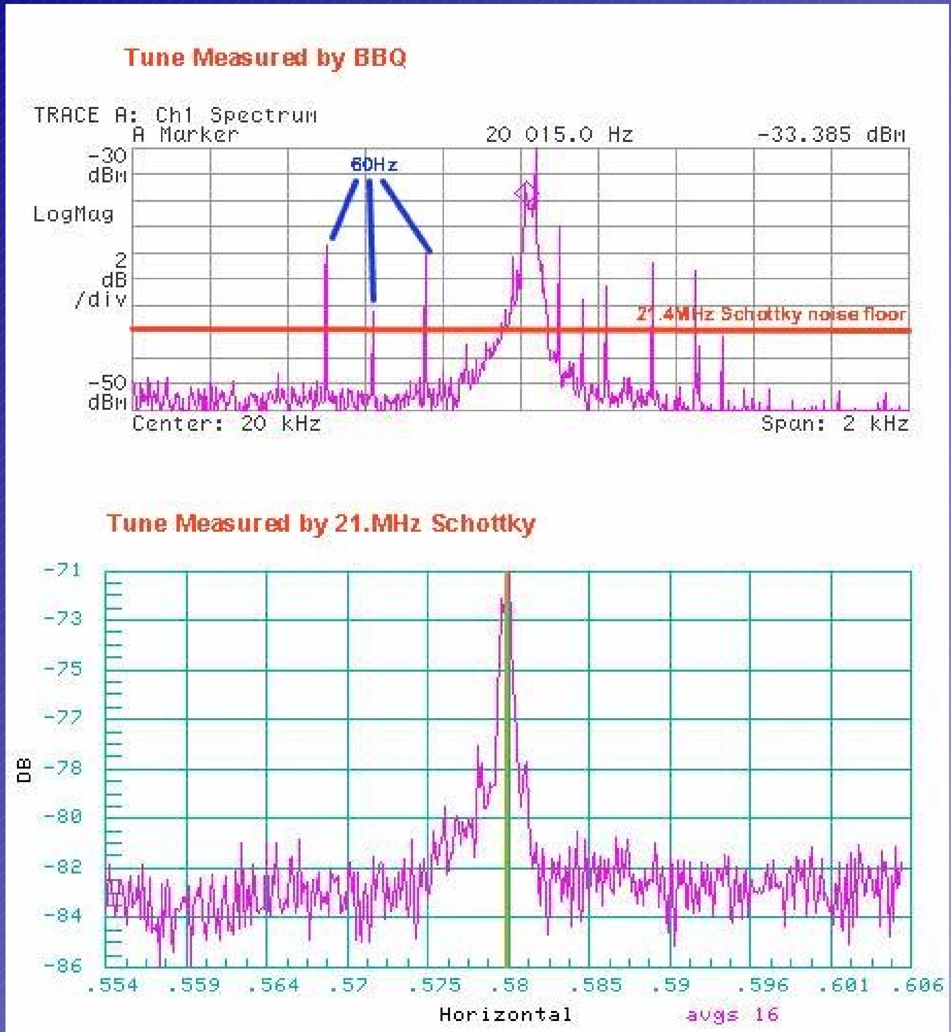


Measured Tunes at Injection



- 36 protons and 12 anti-protons (1 to 4, 13 to 16, 25 to 28)
- Note tune difference

Sensitivity



- 3D-BBQ is between 4 to 6 dB more sensitive than the 21.4MHz Schottky
- 60 Hz seen clearly for the first time
- Source is probably dipoles.
- Seen in Tevatron, RHIC and SPS (50Hz)

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Advantages

- Low cost
  - Simple design.
- Can use any type of pickup if directivity is unnecessary (RHIC, SPS, LHC)
- Insensitive to bunch position.

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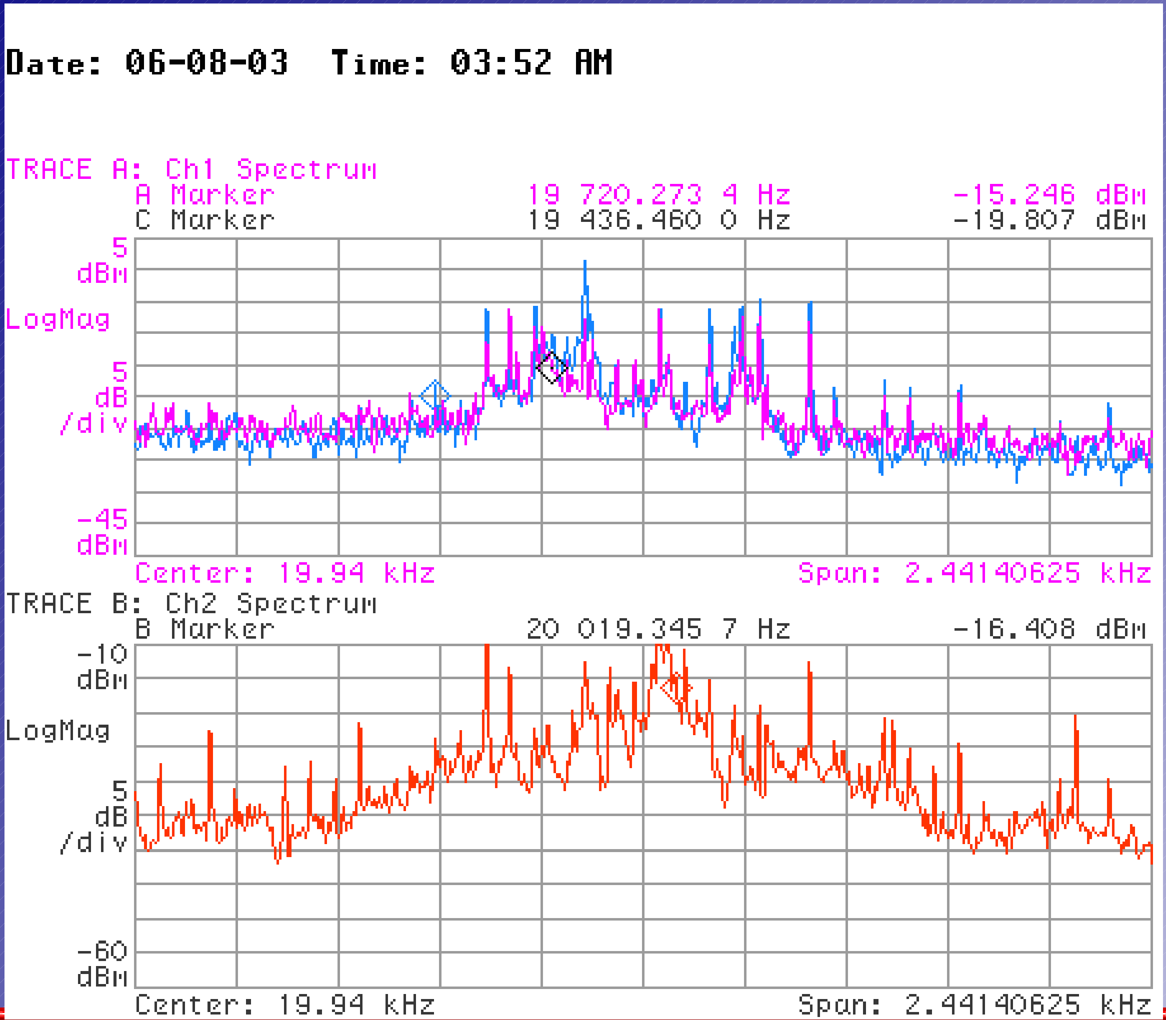
Problems

- Tune would disappear at collisions
  - Happens to both protons and pbars.
- 60Hz lines makes locating of “simple” and yet difficult
  - 60Hz lines tells us where the tunes are.
  - Hard to fit envelope to tell us where tune actually is.

Pbars At Injection



Magenta horz pbars, Ch= 0.5867 (70MHz LPF)
Blue no filters

Red horz protons, Ch=0.5812

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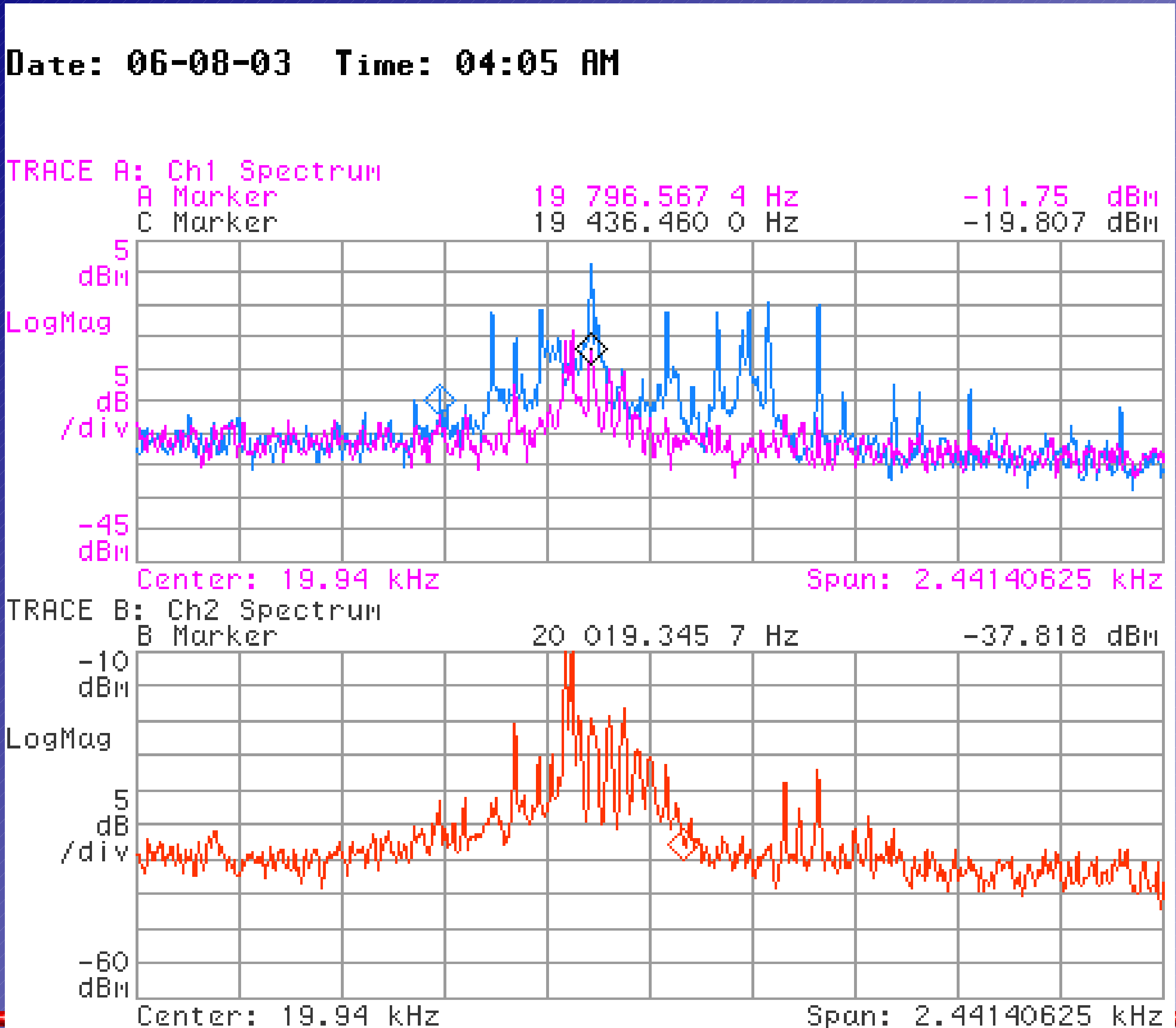
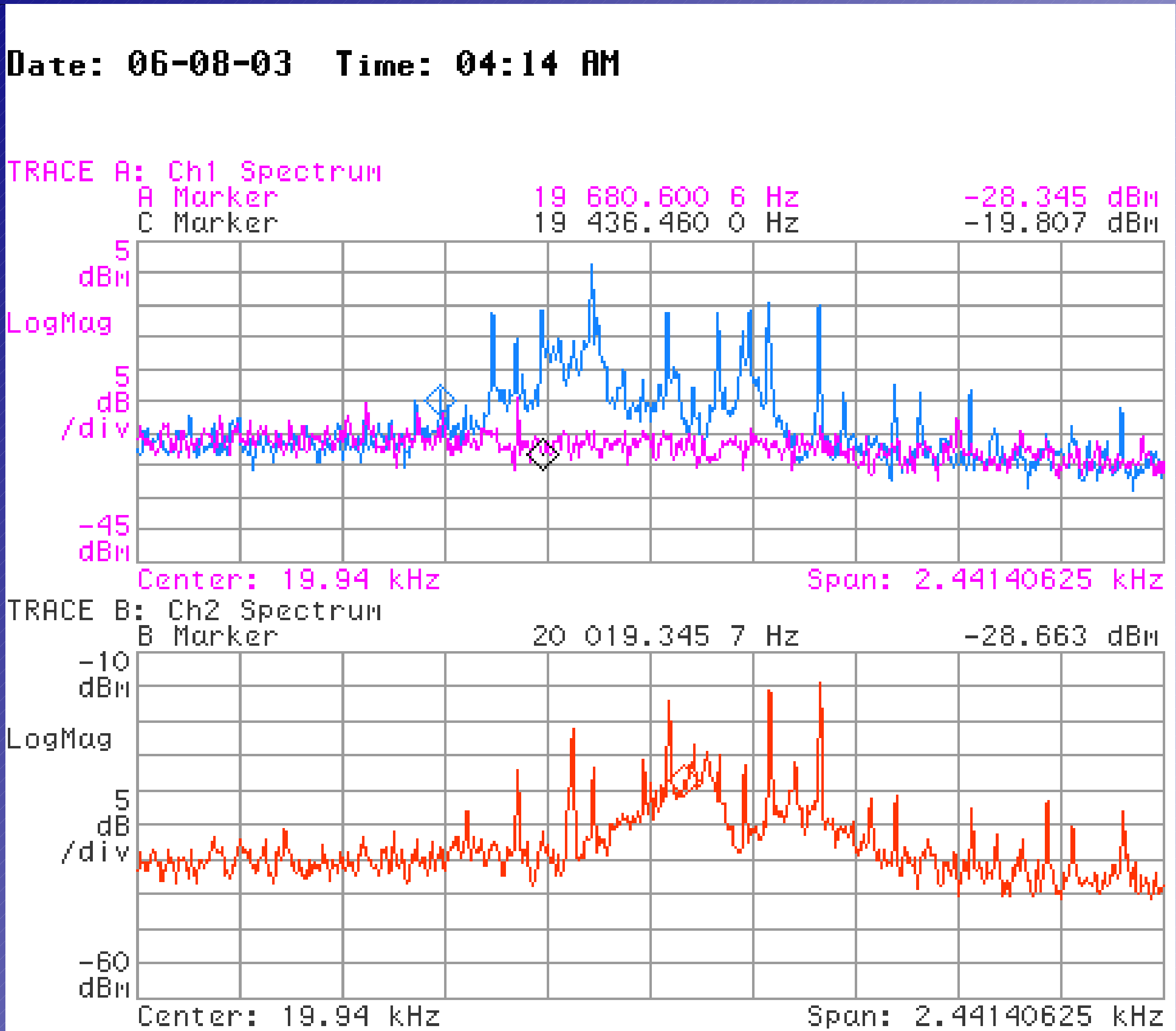
Pbars at flattop



Magenta pbars at flattop
Blue pbars at 150GeV

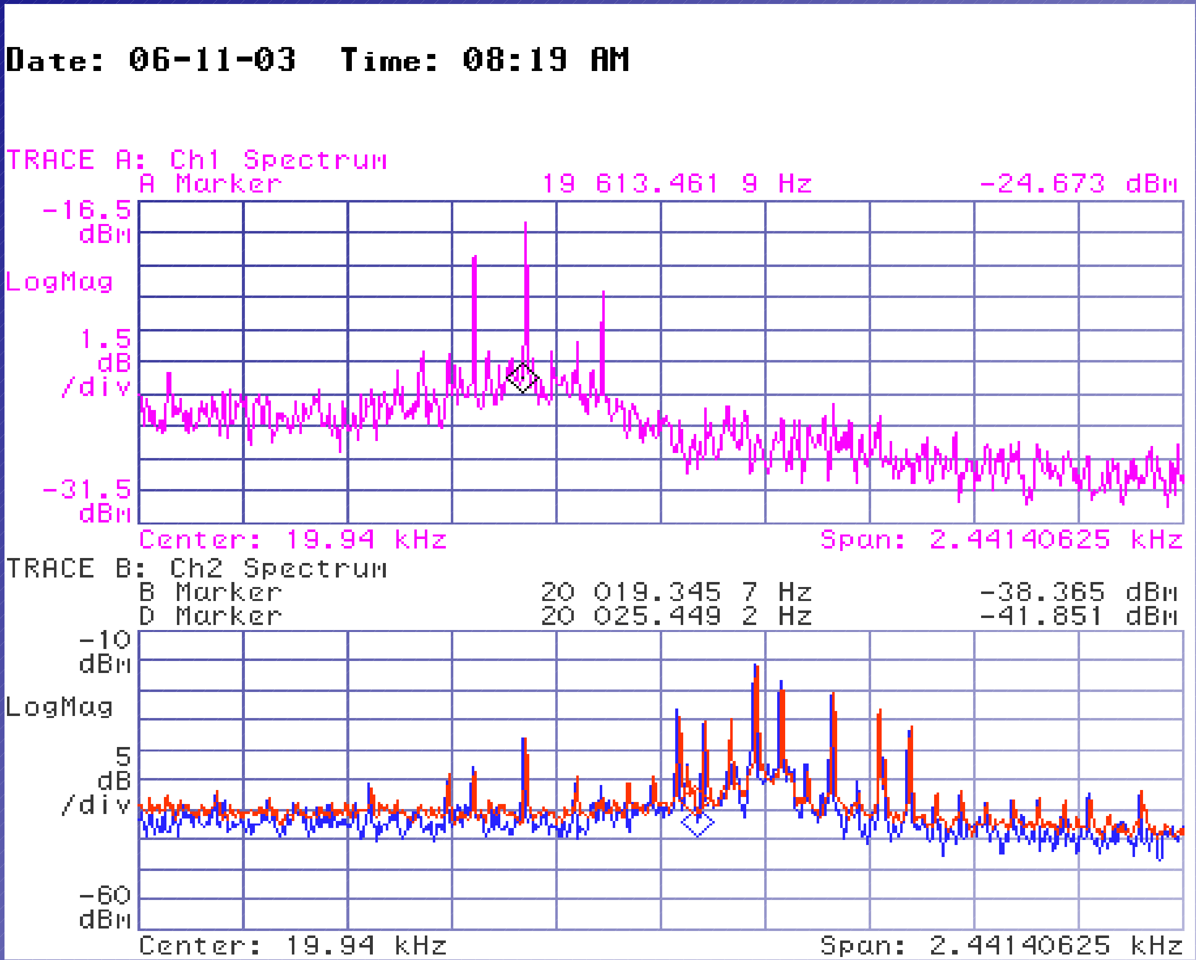
Red protons at flattop

Pbars at collisions



Don't really see pbars at collisions except blips of 60Hz.

Pbars with tickling (another store)



6W of power.
Pbar tunes clearly seen:
Ch pbars = 0.5889
Ch protons = 0.5770

1.7GHz Schottky:
Ch pbars = 0.5895
Ch protons = 0.5783

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3D-BBQ at Collisions

- Adding attenuators and 70MHz filter before the diodes helps to lift the signal out of the noise floor. (approximately 3dB).
- Still dominated by 60Hz lines.

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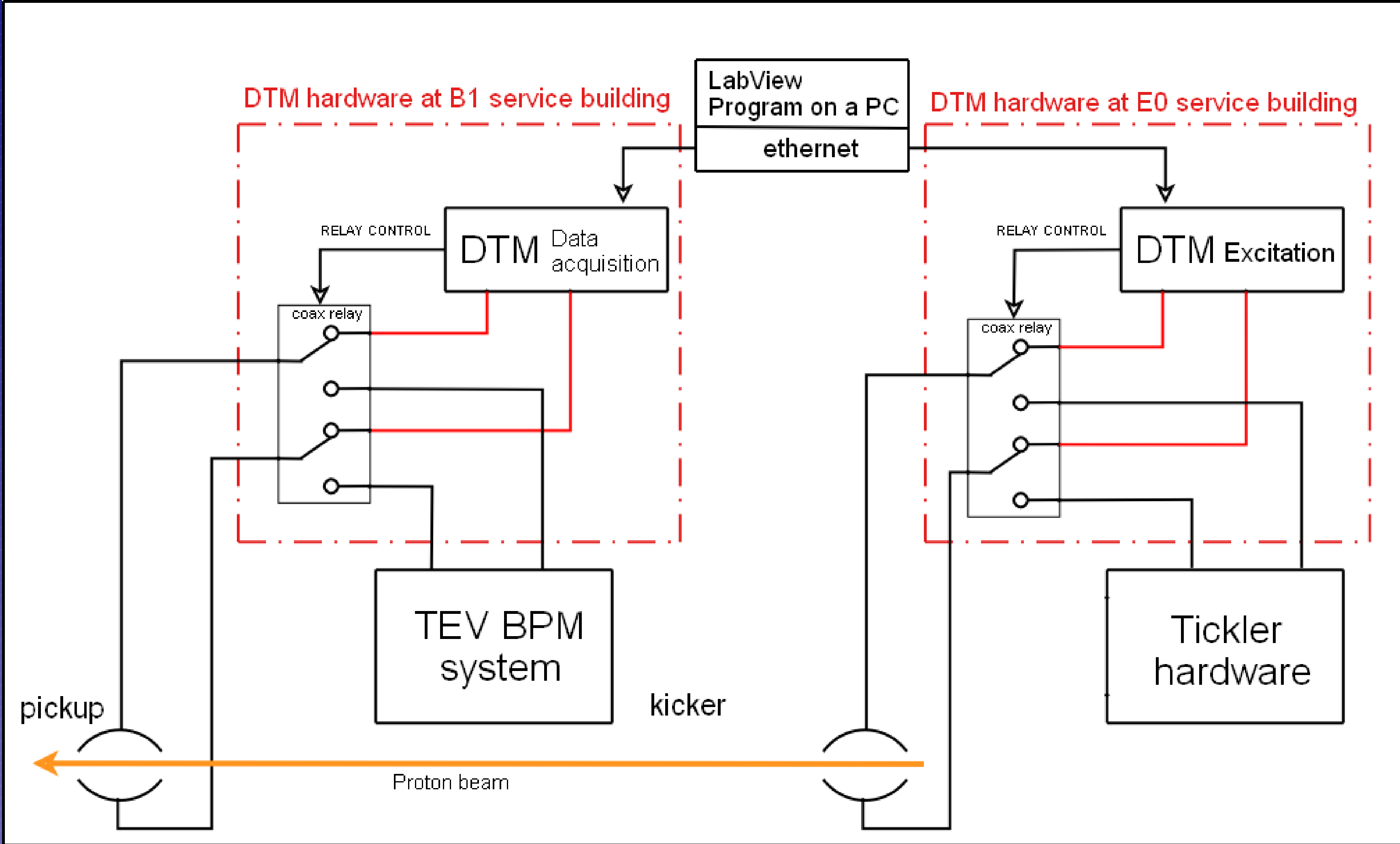
Digital Tune Monitor (not operational)

- Bunch by bunch tune monitor
  - Not operational, expert only.
  - Uses standard Tevatron 30cm stripline BPM.
  - Must tickle beam to see tunes.
  - Does not use gates, but digitizes only where bunches are.

Sharing TEV BPMs and Kickers

Courtesy of V. Kamerdzhiev



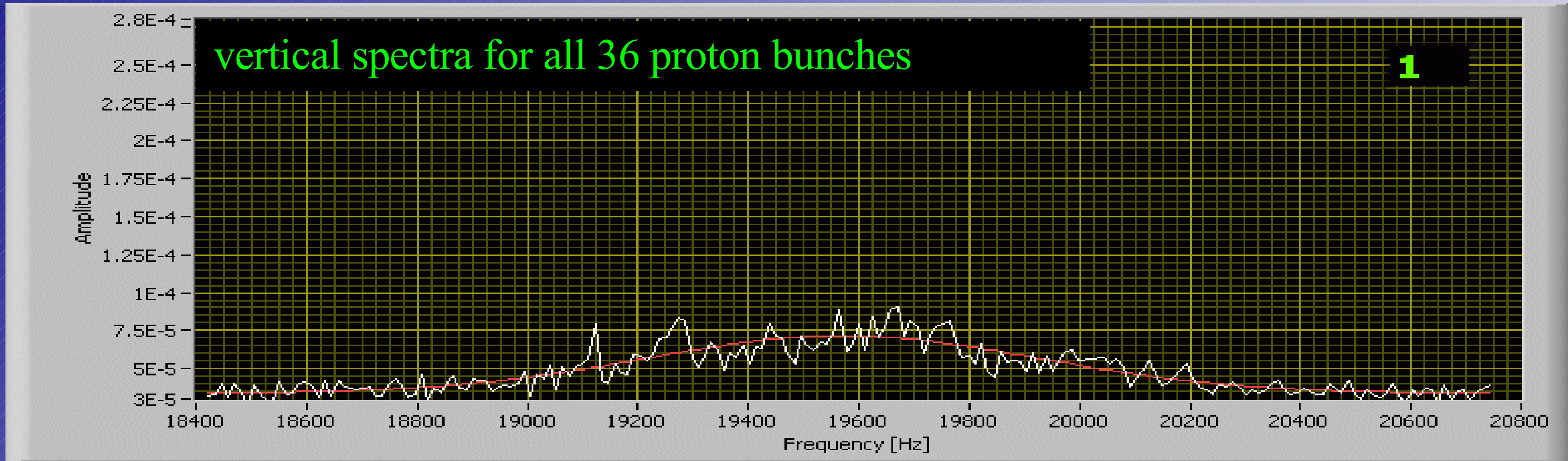
Latest results (store #5301)

Courtesy of V. Kamerdzhiev

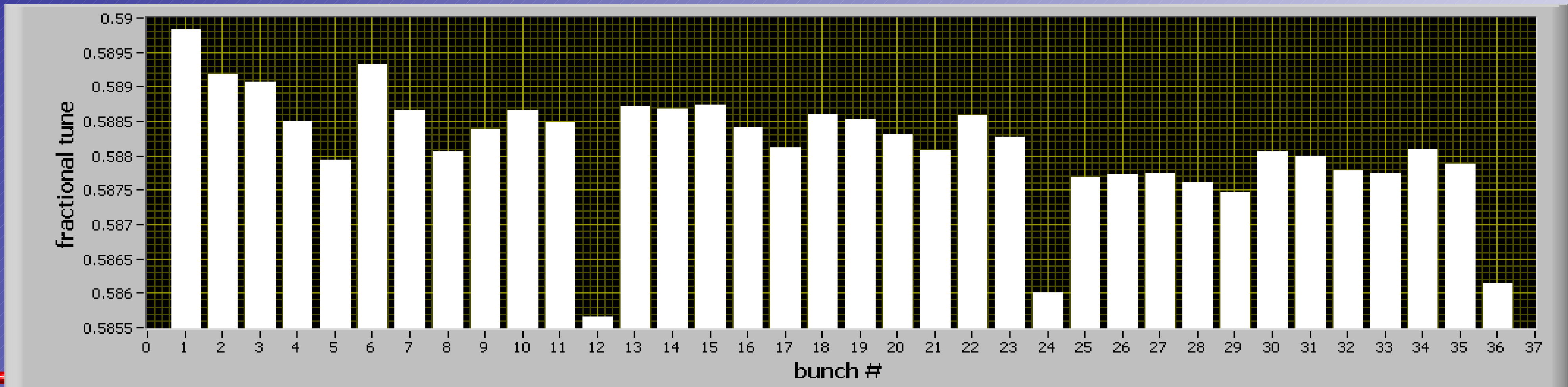
linear scale

gaussian fit

T:STRDUR=20min



The tune distribution is computed in the assumption that there is only one (vertical) peak in the spectrum



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Advantages/Differences

- Very fast because it does not use any gates and so can get all 36 tunes simultaneously.
- Not a Schottky signal like other instruments. It is a coherent measurement.
- Can see pbars.

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Disadvantages and Problems

- Tickling.
  - No emittance blowup seen at collisions because tickling is done in a very short time (2-3 s)
  - Power on beam is very large. 3 to 5W over 5 kHz.
  - No continuous monitoring is possible.
- Slow beam motion gives common mode signal which saturates the amplifiers.
  - Will be fixed with more sophisticated electronics which will adapt to this motion.

Comparison of all 3 Detectors

Detector	Injection	Ramp	Flattop Squeeze	Bunch by Bunch	Coupled Tunes	Accuracy
21.4 Mhz	Y	Y	Y	N	Y	1.00E-004
1.7 Ghz	Y	?*	?*	Y	N	1e-3 to 1e-4
3D-BBQ	Y	Y	Y*	Y	Y	1.00E-004
Tune Monitor	?	?	?	Y	Y	1.00E-004

For 3D-BBQ tunes at collisions S/N gets really poor

For 1.7GHz, tunes tend to either disappear or look coherent when going up the ramp and squeeze.

Conclusions

- 4 different detectors used to measure tune.
  - 2 operational (21.4MHz and 1.7 GHz)
  - 2 not operational (3D-BBQ, Tune Monitor)
- 4 different frequency regimes useful for physics.
  - 21.4MHz
  - 1.7GHz
  - Baseband.